

Future Directions for What We Eat in America–NHANES: The Integrated CSFII–NHANES

Estimation of Usual Intake Distributions of Nutrients and Foods^{1,2}

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ABSTRACT The issue of estimating usual intake distributions using daily intake data as collected by nationwide food consumption surveys is discussed. Of interest are not only the usual nutrient intake distributions based on food intake alone, but also the total nutrient intake distributions that must be based on information on food and supplement consumption. The problems of estimating usual food intake distributions and distinguishing between frequently consumed and infrequently consumed food items are considered. Data needs as well as statistical methodologies available to carry out each of the tasks outlined above are discussed, with particular reference to the integrated National Health and Nutrition Examination Survey that is now in the field. The replicated 24-h recalls should be augmented with a propensity questionnaire to improve on the estimation of intake distributions for infrequently consumed nutrients, supplements and food items. *J. Nutr.* 133: 601S–608S, 2003.

KEY WORDS: • *usual intake* • *adjusted distributions* • *measurement error* • *propensity to consume* • *DRI*

The United States government began collecting dietary intake data in the 1930s. Since then, information on the usual intake of nutrients and foods by the U.S. population has been used to design food assistance programs, monitor the nutritional status of groups, establish guidelines for a healthy diet and in general serve as a blueprint for activities as diverse as government interventions and basic research. Usual intake of a nutrient or a food is the long-run average intake of the food or the nutrient by an individual. It is the usual rather than the daily intake of a nutrient or a food that is often of interest to policy makers and researchers. In particular, investigators interested in assessing intake at the group or population level will require a reliable estimate of the usual intake distribution in the group or the population of interest. Estimation of usual intake distributions of various dietary components is the main topic for discussion in this contribution.

Several national food consumption surveys have been conducted in the past 25 y. Although sample sizes have tended to be adequate for most gender and age groups, the number of observations collected on each individual in the sample has been decreasing over time because of the cost of collecting the data and of respondent burden. In fact, two of the most recently released dietary intake surveys, the most recent Continuing Survey of Food Intake by Individuals (CSFII)⁴ and the third National Health and Nutrition Examination Survey (NHANES III), collected only two observations on sample individuals and for NHANES III the proportion of individuals with a second dietary intake observation was only ~5%.

The small number of daily observations on sampled individuals creates some challenges because dietary intake data are notoriously difficult to analyze. Naïve statistical analyses based on one or two daily observations for each individual in the sample may result in misleading summaries and conclusions; therefore, it is important to carry out the appropriate analyses of the data to uncover the wealth of information contained in nationwide dietary intake surveys.

What are the characteristics of dietary intake data that pose challenges for the analyses mentioned above? Underreporting of energy and components such as alcohol and fats and overreporting of foods perceived to be socially acceptable such as fruits and vegetables have been reported many times in the literature (1–3) and are a serious shortcoming of all standard survey instruments used in dietary intake surveys. Although a

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⁴ Abbreviations used: CSFII, Continuing Survey of Food Intake by Individuals; DRI, Dietary Reference Intake; EAR, Estimated Average Requirement; ISU, Iowa State University; NCI, National Cancer Institute; NHANES, National Health and Nutrition Examination Survey; NRC, National Research Council; UL, Tolerable Upper Intake Level.

clearly significant source of error, inaccurate reporting of intakes cannot be corrected via statistical adjustments, at least with the current level of information on the causes and patterns of incorrect reporting among various population subgroups. What can be effectively addressed via the appropriate survey design and statistical analyses are attributes of dietary intake data that include the day-to-day variability in intakes, correlation of intakes reported over consecutive days, effect of nuisance factors on intake (such as day of week, interview sequence and method), nonnormality of reported intakes and survey nonresponse. Appropriate approaches to account for these and other attributes of dietary intake data when estimating usual intake distributions of nutrients and foods are discussed here.

The problem of estimating the usual intake distributions of nutrients considering only food sources of intake has been discussed in some detail in the past few years (4–9). Here we revisit the issue and discuss in addition the problem of estimating the usual nutrient intake distribution when both food and supplement sources are considered. Despite the increasing proportion of individuals' nutrient intakes that is derived from supplements for some nutrients, surprisingly little has been published on how to combine the two intake sources to estimate a distribution of total nutrient intake (8,10). This can perhaps be explained by the scarcity of information available on supplement intake at the individual level. The problems of estimating usual food intake distributions and distinguishing between frequently consumed and infrequently consumed food items are also considered here.

Dietary intake data

The daily intake of a nutrient or a food, which we denote Y_{ij} , is the intake observed for individual i on day j . Survey instruments such as 24-h recalls, food diaries or records are designed to capture daily intake. Daily intake exhibits variation from day to day within an individual, although in general it is accepted that the mean of a large number of daily intakes for an individual is a good estimator of the individual's usual intake of the nutrient or the food. Thus, in statistical terms, we define the usual intake of a nutrient or the food to be the expected value of the daily intake for that individual, or

$$y_i = E\{Y_{ij} | i\}$$

Survey instruments such as food frequency questionnaires attempt to capture usual intakes but typically fail to do so accurately. Recent studies (11–13) showed that the correlation between usual energy intake as measured by doubly labeled water and as measured by a food frequency questionnaire can be remarkably low, thus putting in question the value of food frequency questionnaires for quantitative dietary assessment at the group level of the type discussed in this article.

The definition of usual intake above is implicit in the simple measurement error model proposed by the National Research Council (NRC) (4) that establishes that daily intake is a deviation of usual intake, where the deviation is called a measurement error:

$$Y_{ij} = y_i + e_{ij} \quad (1)$$

Here, y_i has mean μ_y and variance σ_y^2 and e_{ij} has mean 0 and variance σ_e^2 . The variance σ_e^2 represents the day-to-day variance and σ_y^2 represents the individual-to-individual variance in intakes, or the variance of the usual intakes. Under the model, the variance of daily intake has two components: the individual-to-individual and the day-to-day variability in intakes.

Researchers and policy makers who wish to assess the intake of foods or nutrients in groups or populations are typically interested in the distribution of usual intakes in the group or population. That is, they are interested in estimating the distribution of the y_i from the observed Y_{ij} .

One simple approach to estimating usual intake distributions consists of using the mean of several days of daily intake for each individual in the group as an estimator. Unfortunately, although intuitively appealing, this simple approach is likely to result in an inaccurate estimate of the usual intake distribution because the presence of the day-to-day variability in intakes can greatly inflate the variance of the distribution of individual means. Consider the typical situation, where 2 d of intake are obtained on each individual in a nationwide survey. If Y_i denotes the mean of the 2 d of intake for individual i , then under model 1 the variance of the 2-d mean is

$$\text{var}(Y_i) = \sigma_y^2 + \frac{\sigma_e^2}{2}$$

If, as is often the case, the day-to-day variance of intake is larger than the individual-to-individual variance, the distribution of 2-d means will have a variance that reflects more than just the individual-to-individual variability in intakes. For example, in the case of some vitamins such as vitamins A, E and C, the day-to-day variability in intakes can be 4 or even 6 times as large as the individual-to-individual variability (14,15). For nutrients such as protein and energy, which are consumed more regularly, the day-to-day variability in intakes is typically about as large as the individual-to-individual variability. Thus, any dietary assessment based on the distribution of the mean of a few days of intakes will be biased, sometimes severely so. That bias can be reduced by greatly increasing the number of daily intakes that are collected on each individual in the sample. For example, if instead of two daily intakes we were to collect 10 or even 20 d of intake on each individual in the sample, the variance of the mean of those days would begin approaching the individual-to-individual variance, even for nutrients that are not consumed regularly. This approach, however, is impractical in terms of both cost and respondent burden. Therefore, the only alternative available to practitioners is to apply statistical adjustments to partially remove the day-to-day variance from the daily intakes. The goal is to obtain an estimate of the usual intake distribution with the correct spread (i.e., variance).

Applying a statistical adjustment to remove the day-to-day variance from daily intakes would be simple if daily intake could be assumed to be normally distributed. Unfortunately, the normality assumption is untenable for most nutrient intake distributions, which typically exhibit a long tail to the right. Furthermore, the distribution of daily intakes of food items that are not consumed regularly exhibits a spike at zero, corresponding to individuals who never consume the item and to individuals who did not consume the item during the 2 interview days. Day-to-day variability in intakes is often not homogeneous across individuals but is instead associated with the individual's level of intake. Thus, methods for estimating usual intake distributions must be able to account for the heterogeneous day-to-day variability in intakes. In the case of infrequently consumed items, the methods must also be able to distinguish between the real zero intakes that correspond to nonconsumers and the occasional zero intakes that correspond to consumers who happened to skip that particular food item during the interview days. Reliable estimation of usual intake distributions require that the appropriate data be available and that adequate statistical methods be used for analyses.

Estimating usual nutrient intake distributions using food intake data

The implementation of any of the statistical adjustment methods that remove the day-to-day variability from daily nutrient intakes requires that a replicate observation be available on at least some individuals in the sample (4–6,8). The question of how many individuals should have a replicate observation for accurate estimation arises immediately and is difficult to answer in the abstract. The replicate observations contain information necessary for estimating the day-to-day variance component in daily intakes, a key parameter in the statistical adjustment procedure. If this variance is not reliably estimated, then the observed daily intakes may shrink too much or too little toward the group mean intake, and the resulting estimated usual intake distribution may have a spread that does not accurately reflect the individual-to-individual variability in intakes. A simple rule of thumb is the following: nutrients that are consumed more or less regularly, such as energy, protein, fats, iron and calcium, are typically easier to analyze than nutrients that are present in only some foods and are therefore consumed infrequently, as is the case for most vitamins and micronutrients. By “easier” we refer to the fact that if a small proportion of individuals in the sample have been interviewed twice, then it is likely that the estimated distributions of the vitamins and the micronutrients are less accurate than those that correspond to the macronutrients and other more frequently consumed nutrients.

The CSFII and the integrated NHANES survey now in the field will collect a replicate 24-h recall for each individual in the sample. These data, with adequate statistical treatment, will provide reliable estimates of usual nutrient intake distributions for most nutrients and for most gender and age groups. Because they are infrequently consumed, nutrients such as lycopene, β -cryptoxanthin and α -carotene may require more information than that provided by the two 24-h recalls. These nutrients together with foods such as green leafy vegetables, shellfish and vitamin C-containing fruits and with supplements that are not consumed daily require additional intake information as well as an extension of the statistical methods available for nutrients that are regularly consumed and are discussed later.

The need for adjusting daily intake distributions via statistical methods was first proposed by NRC (4). The approach proposed by NRC consisted of shrinking the individual mean intakes toward the group mean intake, where the shrinkage factor was the ratio of the individual-to-individual SD to the total SD of daily intake. More precisely, the adjusted individual usual intake estimator proposed by NRC is calculated as follows:

$$\tilde{y}_i = Y_{..} + \frac{\sigma_y}{(\sigma_y^2 + \sigma_e^2)^{1/2}} (Y_i - Y_{..}) \quad (2)$$

where as before, Y_i denotes the observed individual mean intake and $Y_{..}$ now denotes the general group mean intake. This approach is intuitively very appealing; if the day-to-day variance σ_e^2 is close to zero, the best estimate of the usual intake distribution is the distribution of the individuals' observed mean intakes. However, if the day-to-day variability is very large relative to the individual-to-individual variance σ_y^2 , the estimated individual usual intakes are strongly shrunk toward the general group mean, which results in an estimated usual nutrient intake distribution with a very small variance, corresponding to the relatively small individual-to-individual component in the total variance of daily intakes. In other

words, the smaller the nuisance day-to-day variance, the closer the adjusted intake distribution will be to the distribution of individual means. The larger the “nuisance variance,” the more the estimated usual intake distribution will resemble a spike at the general group mean intake.

The shrinkage estimator of individual usual intake that was proposed by NRC has good statistical properties only if the distribution of daily intakes can be assumed to be normal. Because in most cases daily intakes are not distributed as normal random variables, the NRC committee proposed that a log transformation be used on the daily intakes in an attempt to meet the normality assumption. The estimated usual intakes are then transformed back into the original scale by simply applying the inverse (in the case of the log, the exponential) transformation to the adjusted individual intakes. In expression 2 both the individual mean Y_i and the group mean $Y_{..}$ (as well as the two variances) would be computed from the log-transformed daily intakes or $\log(Y_{ij})$. The adjusted usual intakes \tilde{y}_i would then be transformed back into the original scale by applying the inverse transformation, or $\exp(\tilde{y}_i)$.

Although the NRC approach is simple to implement, it may result in inaccurate estimation of usual nutrient intake distributions because several of the assumptions behind model 1 on which it is based are not met by the procedure just described. For example, the log transformation often does not produce normally distributed transformed daily intake data, so other transformations, including some beyond the usual power family, may be needed for some nutrients. Perhaps more significant, however, is the bias that may be introduced into the estimator of the usual intake distribution by applying the simple inverse transformation to the estimated individual usual intakes as the NRC report (4) recommends. The mean of a nonlinearly transformed variable is typically not equal to the transformation of the mean of the variable, so a procedure that uses the same transformation and its inverse on observations and means will typically result in biased estimates of quantities in the original scale.

Researchers at Iowa State University (ISU) proposed a statistical adjustment procedure (5) that better accounts for some of the characteristics of dietary intake data. The ISU method (5,8) consists of essentially the same steps included in the NRC method:

1. Daily intake data are first transformed into the normal scale by applying a two-step transformation procedure. In the first step, daily intake data are transformed using the best possible power transformation, where “best” here refers to how closely the distribution of the power-transformed daily intakes approaches a normal distribution. In the second step, power-transformed daily intakes are mapped into the normal scale via a cubic spline transformation.
2. Once daily intakes are transformed, the ISU method proceeds in a manner very similar to the NRC approach by computing an estimated usual nutrient intake in the normal scale for each individual in the sample. The ISU method, however, allows for the case where the day-to-day variance in daily intake is heterogeneous across individuals.
3. Perhaps the biggest difference between the two procedures is found in the last step, where estimated usual intakes are transformed back into the original scale. Rather than implementing the naïve back-transformation, the ISU method estimates a mean back-transformation that greatly reduces the bias that can be introduced when proceeding as the NRC recommends.

The estimated individual usual intakes in the original scale can then be used to obtain an empirical estimate of the usual nutrient intake distribution. From this, quantities of interest such as mean, median, SD and percentiles of usual intake can be estimated in a straightforward manner. Standard errors of all those quantities, which take into account the complex design of dietary intake surveys, can be obtained using replication methods such as the bootstrap or balanced repeated replication. Software is available to carry out these computations. The program SIDE (Software for Intake Distribution Estimation), which runs on a variety of platforms, is available from ISU (16).

What are the consequences of not adjusting daily intakes? As mentioned above, estimating the distribution of usual intakes as the distribution of 1-d intakes or even as the distribution of 2-d mean intakes can result in distributions with too large a variance. As a consequence, estimates of quantities such as the prevalence of nutrient inadequacy in a group may be significantly biased when using the probability approach (8) or the Estimated Average Requirement (EAR) cut-point method approach (7,8,17) for estimating prevalence. Briefly, the EAR cut-point method for estimating the prevalence of nutrient inadequacy establishes that, given certain assumptions, the proportion of individuals in a group whose usual intakes do not meet requirements can be estimated as the proportion in the group whose usual intakes do not meet the EAR for the nutrient. The method produces a reliable estimate of the prevalence of inadequacy when the distribution of requirements for the nutrient is symmetric around the EAR, the individual-to-individual variance of requirements is less than the individual-to-individual variance of intakes and intakes and requirements are independent. In addition, the performance of the method improves when the true prevalence of inadequacy in the group is not too small or too large (8).

For example, we estimated the usual nutrient intake distribution of vitamin B-6 among women aged 19–50 y using the 1994–1996 CSFII. The EAR for this gender and age group is 1.1 mg/d. Thus, an estimate of the prevalence of vitamin B-6 inadequacy among women aged 19–50 y is obtained as the proportion of women whose usual vitamin B-6 intake is below 1.1 mg/d (7,8,17). In **Figure 1**, we show the estimated usual vitamin B-6 intake distributions that are obtained using either one 24-h recall or both 24-h recalls adjusted using the ISU method.

Notice that the two estimated distributions have noticeably different variances and consequently have tails of different lengths. The lower, more spread out distribution was obtained using only one 24-h recall for each woman. The estimated prevalence of vitamin B-6 inadequacy based on this distribution is ~37%. The taller, narrower distribution was obtained using the ISU method and the two 24-h recalls available for each woman. The estimated prevalence in this case is ~20%. The difference between these two estimates is striking and can potentially lead to very different conclusions and even policies. For nutrients such as vitamin A and E that can exhibit even larger day-to-day variability, the difference between a naïve estimate of prevalence and an estimate using more appropriate statistical approaches can be even more dramatic.

The ISU method produces reliable estimates of usual intake distributions of most nutrients (8,9). The new integrated NHANES survey, with a replicate observation on each sample individual, collects the data that are needed for implementation of the method. Thus, for estimating the usual intake distribution of nutrients, both the data and the methodology are available. Additional challenges arise, however, in the case

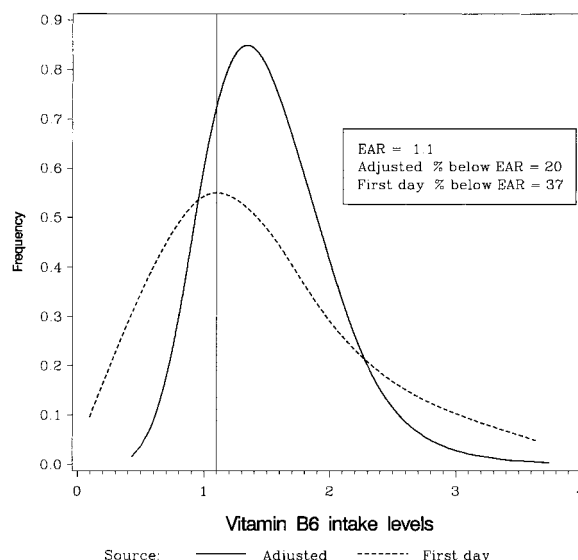


FIGURE 1 Estimated usual intake distribution of vitamin B-6 for women aged 19–50 y. Using only one 24-h recall for each woman gave a flatter curve. Using two 24-h recalls and the ISU method for removing day-to-day variability from daily intake gave a taller estimate. The proportion of individuals with inadequate intakes is estimated using the Estimated Average Requirement (EAR) cut-point method and the two estimates of the usual nutrient intake distribution. (Source: 1994–1996 CSFII.)

of nutrients such as lycopene, whose intake pattern resembles that associated with an infrequently consumed food item. For those nutrients, additional data and an extension of the methodology described above may be needed for accurate estimation of usual intake distributions.

Estimating usual nutrient intake distributions using food and supplement intake data

For some nutrients such as vitamin C and calcium, the proportion of intake from supplement sources has increased in the past few years (18). Approximately 33% of Caucasian women aged 19–50 y reported consuming supplements during NHANES III (10); 23% of African-American women and 18% of Hispanic women reported consuming supplements. Because these percentages are based on a survey that is over a decade old, they are likely to be even higher today. Therefore, collecting the data and developing the methods that permit estimating usual total nutrient intake distributions is likely to be of interest to practitioners and policy makers.

Few data on a national scale are available for characterizing supplement intake patterns. The CSFII has not collected information on individual daily supplement intake beyond some general questions on frequency. In NHANES III detailed questions about specific supplements and doses were posed to sampled individuals, but the instruments used to collect the supplement intake data were meant to capture the usual supplement consumption rather than the daily intake. These data do not provide enough information to determine whether nutrient intake from supplement sources is also subject to day-to-day variability. If so, then it is important to determine whether the ratio of day-to-day variance to total intake variance is similar to the ratio that is observed for nutrient intake from food sources.

If nutrient intake from supplement sources for an individual could be assumed to be essentially the same from day to day (as

would be appropriate for individuals who consume the same vitamin pill every day), then obtaining an estimate of total nutrient intake would be simple: for each individual in the sample, add the daily nutrient consumption from both sources and then apply the methods described above to obtain an estimate of the usual total nutrient intake distribution. If day-to-day variability in supplement intake is negligible relative to the individual-to-individual variability in intake, then the frequency instrument currently in use in NHANES to collect supplement intake data might be adequate.

In the absence of information beyond that provided by the frequency instrument on supplement intake, large (and untestable) assumptions must be made when combining food and supplement intake data to estimate total nutrient intake. One possible approach (8,10) consists of the following steps. Using only food intake data, apply the methods described above to obtain adjusted individual usual intakes in the original scale. From the frequency information on supplement intake, compute a daily individual intake of nutrient from supplement sources by dividing the dose reported by the individual into its frequency. The sum of both intakes, one adjusted and one not adjusted, constitutes an estimate of the individual's daily usual total nutrient intake that can then be used for estimating the distribution of total nutrient intake. Quantities of interest such as mean, median and percentiles of intake can be obtained from the distribution. Standard errors of all those quantities can be obtained using a replication method such as the bootstrap. This approach is unsatisfactory, however, because it assumes that the day-to-day variability in nutrient intake from supplement sources is zero. This is unlikely to be the case; the variance of the usual total nutrient intake distribution may not accurately reflect the individual-to-individual variance in total usual intake, and this may result in biased estimates of quantities such as the prevalence of nutrient inadequacy or the proportion of individuals exceeding the Tolerable Upper Intake Level (UL). The mean total nutrient intake can still be reliably estimated via the approach just described.

The day-to-day variance in supplement intake may not be negligible. If this is so, a frequency instrument cannot capture the daily supplement intake and furthermore does not allow for estimation of the day-to-day variance in supplement intake. It would appear, therefore, that replicate 24-h recalls to capture daily supplement intake would provide the necessary information for combining food intake and supplement intake data in a statistically defensible manner. If replicate 24-h recalls are extended to collect supplement intake data together with food intake data, then daily intakes of nutrients from food and supplement sources can be combined before adjustments are made. The statistical adjustment methods would then be applied to the total daily intakes collected for each of the individuals in the sample and the adjusted distribution would reflect total usual nutrient intake.

One potential shortcoming in the approach just described is that it does not lend itself well to the scenario where a considerable proportion of supplement consumers take supplements only occasionally. Consider, for example, the case where the population consists of three types of individuals: those who never consume supplements, those who consume supplements infrequently (e.g., once weekly or only when feeling ill) and those who consume supplements regularly (daily or every other day). If two nonconsecutive 24-h recalls are administered to each sample individual, the observed distribution of nutrient intake from supplements will have a spike at zero corresponding to the nonconsumers and to some of the occasional consumers who by chance did not consume the supplement during either of the 2 survey days. If the occasional

consumers make up a nonnegligible portion of the population, then additional intake data that may allow separating the true zeroes from the occasional zeroes are needed. In this light, a propensity questionnaire of the type under pilot testing by the National Cancer Institute (NCI) for collecting information on the propensity to consume food items such as green leafy vegetables might provide the information needed to separate true nonconsumers from occasional consumers before analysis.

Reliable estimates of total usual nutrient intake distributions might reveal unexpected trends in nutrient intake. For example, individuals who already appear to consume adequate amounts of nutrients from supplement sources tend to be regular supplement consumers as well (18,19). In fact, some researchers have shown that indicators of a healthy lifestyle are positively correlated to supplement consumption. Consistent with these findings, a comparison of usual nutrient intake distributions estimated for women aged 19–50 y from food intake data alone or from food and supplement intake data for vitamins C and E using NHANES III data shows the following: as expected, mean intake is higher when nutrient intake from supplement sources is added to nutrient intake from food sources. The prevalence of nutrient intake as estimated by the proportion of individuals with usual intake below the EAR is only slightly smaller when total nutrient intake is considered. That is, the left tail of the intake distribution, which corresponds to individuals with relatively low nutrient intake, is not noticeably pulled toward the center of the distribution when supplement intake is accounted for. This is because individuals with low nutrient intake from food sources do not tend to be regular supplement consumers. The right tail of the distribution is stretched further out because individuals who already show relatively high nutrient consumption from food are also the ones that tend to consume supplements. Notice that, as a consequence, the proportion of individuals whose intakes exceeded the UL for the nutrient may also be larger.

The mean, SD and selected percentiles of the usual intake distributions of vitamins C and E for the group of women aged 19–50 y obtained from the NHANES III survey are shown in Table 1. The distribution of usual nutrient intake from food sources was obtained using the ISU method. When supplement intakes were also considered, the daily intakes were adjusted using the rough approach that was described earlier.

The supplement intake data that are collected via frequency questionnaires greatly limit the range of quantitative analyses that can be conducted. The NHANES survey cur-

TABLE 1

Mean, SD and selected percentiles of the estimated usual intake distributions of vitamin C and vitamin E considering only food sources and food plus supplement sources, for women aged 19–50 y¹

	Vitamin C		Vitamin E	
	Food	Food + supplements	Food	Food + supplements
Mean	90.7	135.8	8.4	22.7
SD	2.2	3.0	0.2	1.1
5th percentile	37.0	39.4	4.8	5.1
25th percentile	61.0	65.6	6.6	7.1
50th percentile	83.2	95.2	8.1	8.8
75th percentile	113.7	138.3	9.9	12.4
95th percentile	169.0	328.8	13.1	41.8

¹ Source: NHANES III. N = 4840.

rently in the field uses the same approach for collecting supplement intake information that was used in NHANES III. Improving the quality of the information obtained on supplements should be possible even under the usual budgetary and practical constraints. We do not trivialize the difficulties inherent in collecting accurate supplement intake data using 24-h recall-type instruments, in particular when interviews are conducted over the phone. Together with supplement intake information, it is also necessary to maintain a complex database that includes nutrient content information on a large and rapidly changing list of brands and products. Implementing significant changes in a survey as complex as the integrated NHANES survey is not trivial, and any potential modification is typically pilot-tested before full implementation. Thus, we propose that a pilot be conducted to evaluate the feasibility of collecting replicate 24-h recalls to capture daily supplement consumption. In addition, a propensity questionnaire similar to the one that has been proposed by NCI should be used to complement the supplement intake information provided by the 24-h recalls.

Although the statistical methodology for analyzing data collected via the 24-h recalls has been developed and validated, the methods that would take advantage of the additional information contained in the propensity questionnaires are still under development. Dodd and collaborators at NCI (K. W. Dodd, unpublished results, 2002) have proposed a method for combining propensity and daily intake data to adjust the intake distributions of infrequently consumed food items such as fresh milk and leafy green vegetables. If supplement intake patterns resemble those for food intake, then it might be possible to use similar methods to estimate the usual total nutrient intake distributions.

Estimating the usual intake distribution of foods

As in the case of supplements and some nutrients, disaggregated food groupings such as fresh fluid milk, green leafy vegetables and red meat present specific challenges for analyses because they are typically not consumed daily and some individuals never consume those foods at all. In this light, an individual who reports no consumption of a certain food item for a day may be a nonconsumer of the food or may just have not consumed the food during that particular day. Thus, for dietary components that are not consumed nearly daily, it is necessary to extend the simple NRC (4) measurement error model as follows. Suppose that now we let y_i^* denote the usual food intake for individual i on consumption days, so that

$$y_i^* = E\{Y_{ij}|i, Y_{ij} > 0\}$$

Further, let p_i denote the propensity to consume the food by individual i , so that under the assumption that propensity to consume and amount consumed are independent,

$$y_i = y_i^* \times p_i$$

Under the assumption of independence, the usual food intake distribution can be estimated as the product of two distributions: the usual food intake distribution obtained by considering only consumption days and the distribution of propensities to consume the food in the group.

Nusser et al. (20) proposed a two-step approach for estimating usual food intake distributions. First, the ISU method is used to estimate the usual food intake distribution on consumption days. The distribution of propensities to consume is obtained from the observed frequencies of consumption during the survey days. Propensity and amount consumed are assumed

to be independent, and the two distributions are combined in a straightforward manner to obtain the usual food intake distribution. The two drawbacks of this approach are that the independence assumption does not hold for foods such as dairy products, diet soda, alcoholic beverages and fruit (21) and the estimation of the propensity-to-consume distribution is based on the frequency information provided by the 24-h recalls. Nusser et al. developed their approach using a subset of the 1985 CSFII that included four 24-h recalls for each individual in the subsample. Four recalls provide information on the height of the propensity-to-consume distribution at the points 0, 0.25, 0.5, 0.75 and 1, corresponding to individuals who report consuming the item on 0, 1, 2, 3 or 4 d out of 4. From these five observed frequencies, Nusser et al. estimated the mass of the propensity-to-consume distribution at 51 equally spaced points, using an approach based on entropy principles. Dodd et al. (21) extended the Nusser et al. (20) approach and proposed an approach that accounts for linear association between the propensity to consume the item and the amount consumed by the individual. For illustration we estimated the distribution of propensity to consume dark green vegetables, fresh apples, alcoholic beverages and diet soda for a subset of 743 women aged 25–50 y that provided at least four independent 24-h recalls during the 1985 CSFII. The four estimated distributions are shown in Figure 2. Note that the propensity-to-consume distribution for alcohol in this population shows three modes—at 0, 0.4 and 1. This suggests that in this population, the two most typical alcohol consumption patterns among alcohol consumers are to consume alcohol every day or to consume it slightly less often than every other day. In the case of dark green vegetables, the mode of the distribution of propensity to consume in this population is at ~ 0.25 , indicating that dark green vegetables tend to be consumed about once every 4 d.

The design of more current surveys—and of the integrated NHANES survey—calls for only two 24-h recalls for each individual. Two recalls do not provide enough frequency information to reliably estimate the distribution of propensity to consume the item. With the current design, the only heights in the propensity distribution for which the data provide information are those at the points 0, 0.5 and 1, corresponding

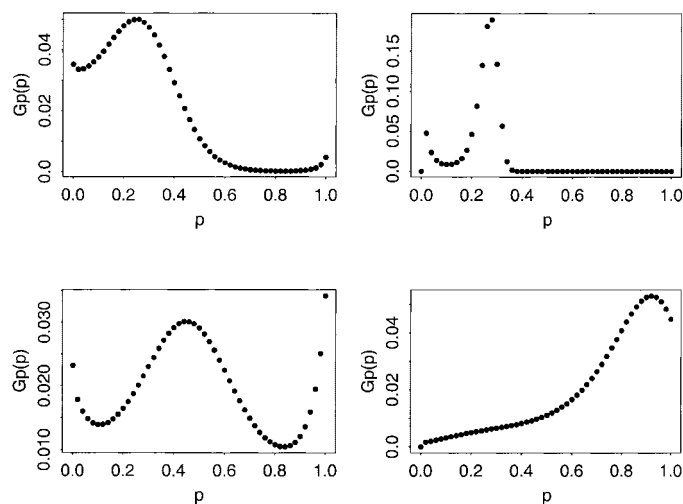


FIGURE 2 Estimated distribution of the propensity to consume dark green vegetables, apples, alcoholic beverages and diet soda for the subset of women aged 25 to 50 y of age who provided at least four independent 24-h recalls during the 1985 CSFII (19).

to individuals that report positive consumption on 0, 1 or 2 d out of 2. Although the Nusser et al. (20) and the Dodd et al. (21) approaches can in principle still be used to estimate the propensity-to-consume distribution from these data, the resulting estimates are likely to be unreliable.

Researchers at NCI (Dodd, Krebs-Smith and others) have initiated testing the efficacy of using a frequency-like instrument as a measure of the propensity to consume. The feasibility of using the propensity questionnaire in the integrated NHANES is currently being pilot-tested (22). Dodd et al. are developing statistical methods for estimating the usual intake distribution of foods that are infrequently consumed, methods that make use of both the propensity questionnaire and the 24-h recalls.

Adding a propensity questionnaire to improve the estimation of the propensity-to-consume distribution is intuitively appealing. The ISU method can produce a reliable estimate of the usual food intake distribution on consumption days, but the Nusser et al. (20) and the Dodd et al. (21) approaches become less reliable as the number of 24-h recalls that are collected on each individual in the sample decreases. Thus, the propensity questionnaires have the potential to fill the data gap that was opened when the number of 24-h recalls in nationwide food consumption surveys was reduced from several to only two. Adding the propensity questionnaire would appear to be a cost-efficient and practical alternative to increasing the number of 24-h recalls from two to at least four.

Although the discussion in this section has focused on the problem of estimating food intake distributions, everything said also applies to infrequently consumed nutrients such as lycopene and β -cryptoxanthin. In addition, the discussion may also apply to supplements, but not enough information on the patterns of supplement consumption is available to conclude this with certainty. Note that frequently consumed foods such as aggregated groups (fruits and vegetables, grains, etc.) behave like frequently consumed nutrients. The usual intake distribution of frequently consumed food items can be estimated using replicate 24-h recalls and any of the adjustment methods described previously; in these cases, the propensity to consume the item is essentially 1 for all individuals, and the propensity questionnaire does not add value for analyses.

Conclusions and recommendations

Reliable estimates of usual intake distributions of nutrients, foods and other dietary components are needed by policy makers, health professionals and researchers. For reasons of cost and respondent burden, it is only practical to collect a few daily intakes for a sample of individuals nationwide. Therefore, the statistical methods that are used to obtain these distribution estimates must be powerful enough to tease information out of scarce data.

Arguably, methods for estimating usual nutrient intake distributions from nationwide food consumption data, at least for nutrients consumed more or less regularly, are available and perform well (9). Smaller sample sizes notwithstanding, it is expected that the daily intake data that will be collected in the combined NHANES survey via two independent 24-h recalls will provide the information necessary to estimate the usual nutrient intake distributions in various gender and life-stage groups. The design of the survey permits implementation of adjustment procedures such as the NRC (4) and the ISU (5) methods for estimating usual nutrient intake distributions. Although methods such as the ISU method for adjusting distributions can effectively account for some of the characteristics of dietary intake data, others—such as the over- and

underreporting of certain foods or the inaccuracies present in the food composition databases—cannot be addressed satisfactorily at this time. The estimates obtained from sophisticated statistical approaches will only be as good as the data that are used for estimation. It is undeniable that the problem of underreporting of energy (1–3) can seriously bias any estimate that is based on self-reported intakes. However, at this time other methods for collecting dietary intake data on a national scale are impractical. A more promising route might be to continue with research on the individual factors that are associated with under- or overreporting of certain foods so that data can then be adjusted using the appropriate statistical procedures.

Although the problem of estimating usual nutrient intake distributions using food sources of nutrients alone is largely solved, the same cannot be said for nutrient intake from supplement sources. Supplement intake data that can be combined with food intake data for estimation of adjusted distributions of total nutrient intake are not available and will not be collected during the first phase of the integrated NHANES survey. As in NHANES III, the integrated NHANES survey that is currently in the field will administer a frequency questionnaire to sample individuals, with the goal of capturing usual or habitual supplement consumption. Unfortunately, several recent studies showed that frequency questionnaires, although effective for qualitative intake assessment, are ill-suited to the type of quantitative assessment discussed here. Thus, it is important to consider pilot-testing alternative data collection systems for supplements for possible implementation in the integrated NHANES survey in the future. The supplement data collection system should include daily supplement intake information (obtained via two independent 24-h recalls) and also information on the propensity to consume supplements in the groups of interest. The latter can be obtained by administering propensity questionnaires that may be similar in design to the frequency questionnaires currently in use. Thus, we recommend that the performance of the combined 24-h recalls (e.g., food plus supplements) and propensity questionnaires be investigated. The challenges inherent in such a strategy are many. For example, whether the current 5-pass method for collecting food intake data is also adequate for supplements is not known. Furthermore, updating and then maintaining a supplement composition database, given the range of products available to consumers and the speed with which they are introduced into the market, is a daunting task.

Finally, we also discussed the issue of estimating usual intake distributions of foods and distinguished between frequently and rarely consumed food items. Methods for estimating usual food intake distributions are available (20,21). Those methods, however, were developed when >2 daily intakes were recorded for at least some individuals participating in nationwide food consumption surveys. For only two observations for each individual in the sample, the reliability of estimates based on the methods mentioned above is in doubt. Researchers at NCI are developing the methodology needed to combine food intake information obtained via 24-h recalls with propensity to consume the food obtained from a propensity questionnaire (Dodd, unpublished results, 2002). As for supplements and other episodically consumed items, distinguishing the nonconsumers of the food from the occasional consumer is important and cannot be achieved with the information provided by the two independent 24-h recalls that will be collected in the integrated NHANES survey. Thus, in lieu of significantly increasing the number of 24-h recalls to be administered to each sample individual, a propensity question-

naire to complement the two 24-h recalls may be the practical and most effective solution.

In closing, it is important to point out that nationwide food consumption surveys such as NHANES will always provide limited information about very specific population subgroups and about infrequently consumed food items. The sample sizes in the combined NHANES survey are unlikely to permit reliable estimation of intake distributions in, for example, pregnant or lactating African-American women who participate in the Women, Infants, and Children program. It is also very unlikely that the survey will permit estimation of the usual intake distribution of, for example, oysters. Food items that are consumed infrequently will most likely not be included in the propensity questionnaires and their consumption will be reported as zero in most of the 24-h recalls. Therefore, general surveys such as NHANES should not be expected to provide the information that would be needed for every task.

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